DEVELOPMENT OF A NONPROPRIETARY FLEXIBLE SHEET EXPLOSIVE

Franklin B. Wells

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JULY 1975

PICATINNY ARSENAL
DOVER, NEW JERSEY

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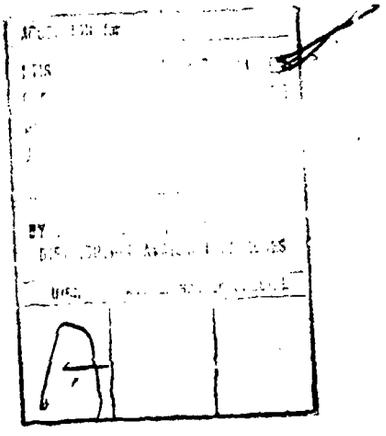

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A nonproprietary, olive-drab colored, flexible sheet explosive based on cyclotrimethylenetrinitramine (RDX) was developed as a replacement for a pentaerythritol tetranitrate (PETN) based flexible sheet explosive (EL 506C, Type II) manufactured under U.S. Patent No. 2,992,087 by E.I. DuPont. The Armed Services procured EL 506C under Military Specification MIL-E-46676 (MU) dated 31 October 1962, which was superseded by MIL-E-46676A (MU) dated		

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20. Continued

17 April 1968. Before completion of the program, the study was expanded to include flexible explosive compositions based on cyclotetramethylenetetranitramine (HMX) and mixtures of RDX and HMX.

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The citation in this report of the names of commercial firms or commercially available products or services does not constitute official endorsement or approval of such commercial firms, products, or services by the United States Government.

OBJECTIVE

To develop a nonproprietary flexible sheet explosive equal to or superior to DuPont's EL 506C.

INTRODUCTION

A proprietary material, EL 506C, manufactured by E.I. DuPont, de Nemours and Company under U.S. Patent No. 2,992,087, was the only source of flexible sheet explosives. The armed services therefore undertook the development of a nonproprietary flexible explosive utilizing RDX in lieu of PETN in June 1963. This work was later expanded to include HMX as a substitute.

From information revealed in the patent and data gleaned from other sources, the composition of EL 506C was found to be approximately 63% fine-grained (0.1-10 micron) PETN, 28.2% Citroflex A4 8% dynamite grade nitrocellulose, and 0.8% olive-drab pigment composed of lampblack and lead chromate. The nitrocellulose contains 12.3% nitrogen and possesses both a high degree of polymerization (D.P. 2000-3000) and a high viscosity (at least 90 seconds for falling ball method outlined in Reference 3). A 4% nitrocellulose solution containing essentially an 8/1 ratio of acetone to ethanol was used for the viscosity determination instead of the 10% solution specified.

Initial efforts were directed towards obtaining sufficient quantities of raw materials for the program. Different batches of EL 506C were procured to act as standards of comparison against which the physical and explosive properties of the experimental compositions could be used. RDX Type B, Class E, and HMX Grade II, Class B, as defined in MIL-R-398C dated 22 August 1962 and MIL-H-45444A (Ord) with amendment 3 dated 31 July 1962, respectively, were selected. The aforementioned standard grades of RDX and HMX will meet the following requirements: 100% through a No. 200 USS sieve and 90% (preferably 97.5%) through a No. 325 USS sieve.

Samples of the required grade nitrocellulose, known commercially as "dynamite grade" nitrocellulose, were obtained from Hercules and DuPont. The Hercules product was selected because it had higher thermal stability than either of the two types of nitrocellulose supplied by DuPont.

Difficulty was encountered in developing a pigment that would impart the desired olive-drab color to the finished product. At first lampblack and lead chromate, available from Arsenal stores, were used; however, the lead chromate was of insufficient color density to impart the desired coloration. Some of the compositions cited in this report were prepared prior to establishment of the coloration requirements and have ratios other than the 1/7 or 1/8 lampblack/lead chromate later established. In the pigment study,

it was found that only pigments known as "chrome yellow, medium" were suitable; however, not all pigments so labeled or all lampblacks give desired results. Materials selected for use include Sherwin-Williams' Chrome Yellow, Medium[1]. Both must be well mixed prior to the addition of the explosive composition to assure uniformity of coloration of the finished explosive.

RESULTS

This work resulted in the development of a nonproprietary flexible explosive equal or superior to the proprietary EL 506C and led to the issuance of U.S. Patents 3,317,361 dated May 2, 1967 and 3,354,010 dated November 21, 1967 covering RDX- and HMX-based flexible sheet explosives.

MATERIALS

A. RDX

The three lots of RDX Type B, Class E (defined in Ref 1) used are listed below:

1. Lot No. HOL-SR-3-57 (A.P.S. 25μ) RDX contained 2.5% HMX.
2. Lot No. HOL-SR-545-62 RDX contained 7.3% HMX.
3. Lot No. HOL-SR-42-57 RDX contained 6.41% HMX.

These three lots were characterized by the test results given below:

Identification		3-57	545-62	42-57
1. Vacuum stability	Temp °C			
(Ml of gas evolved)	100	--	--	0.27
(Ref 6)	120	--	--	0.35
	140	0.83	0.81	--
	150	2.24	4.33	4.52
	160	--	--	7.76

[1]Registered trademark.

		3-57	545-62	42-57
2.	Moisture Content[1] (% water)	8.13	--	--
3.	P.A. impact sensitivity (Ref 6)	--	--	9 inches
4.	Hygroscopicity (%)[2]	--	0.01	0.05
5.	Melting Point (°C) (Ref 1)	200.3	--	193.3
6.	Particle size[3] (Microns)	13	--	11.8
7.	Electrostatic sensitivity (Ref 6) (joules)	--	1.3	2.59
8.	Explosion temperature (°C) (Ref 6)	--	--	240
9.	Friction pendulum (Ref 7)	--	--	N.A.
10.	Ballistic pendulum test (Ref 8)	1.43	--	--

11. Granulation (%) (Ref 1)

Sieve No.	Through	Through	Through
100	99.3	100.0	--
200	97.2	99.3	96.0
230	--	--	96.0
325	91.3	97.8	90.0

[1]Sample dried to constant weight at 100-105°C.

[2]Sample tested at 30°C and 90% RH for 48 hours; the result reported as percent weight gain.

[3]Determined by Fisher Sub-Sieve Sizer.

B. HMX

The one lot of HMX Type II, Class B (defined in Ref 2) used is listed below:

Lot No. HOL-SR-655-61, Batch BF385. This HMX contains 1.55% RDX. Only two tests were conducted on this material.

1. Electrostatic sensitivity 4.3 joules

2. Granulation (%)

Sieve No.	Through
120	100.0
200	97.8
230	97.6
250	95.0

C. PETN

The PETN used for comparative purposes bore the designation PETN, 10-12 micron, P.O. 02639/A.

D. Citroflex A4

Citroflex A4 was subjected to vacuum stability tests to ascertain its relative thermal stability. The results of these tests are given below for 5-gram specimens.

Vacuum stability	Temp °C	Ml Gas Evolved
	100	0.31
	110	0.30
	120	0.33
	130	0.41

E. Nitrocellulose

Five lots of "dynamite grade" nitrocellulose were obtained from Hercules, Inc.

1. Lot No. X-1534-10-1
2. Lot No. 923
3. Lot No 942
4. Lot No. 947

5. Lot No. 983B

Two lots of nitrocellulose were obtained from E.I. DuPont de Nemours and Company.

1. Lot No. D2E

2. Lot No. D2W. This material was prepared from wood cellulose.

The different lots of nitrocellulose were characterized by the test results given in Table 1.

F. EL 506C

A complete characterization of the three lots of DuPont's flexible explosive (14 OT 11, Aug 63; DU-L-01, June 63; and 12-OC-01) appears in Picatinny Arsenal Technical Report 4612, "Some Properties of the Flexible Explosive EL 506C, Type 2," February 1974 (Ref 11). The values listed in test results are the average values for this material.

EXPERIMENTAL PROCEDURES

In general, batches of flexible sheet explosive were prepared by initially mixing the solid materials, whether water or solvent-wet or in the dry state, with ethanol and/or other solvents, forming a paste. After the plasticizer was added with vigorous stirring, the mixture was aged before rolling on a mill at 130-135°F with a gap setting of 0.010 - 0.020 inch until all volatiles were removed. The thin sheets obtained were consolidated to form sheets of desired thicknesses such as 0.08, 0.16, and 0.25 inch. Depending upon the particular composition being processed, it was empirically found that gap settings of 0.210 - 0.240 inch were required to obtain sheets 0.250 $\pm$ .005 inch thick at a roll temperature of 135°F.

In the preparation of small experimental laboratory batches, up to 500 grams, anydrous ingredients were generally used. In the preparation of larger batches in plant scale equipment, the particulate explosive, i.e., RDX and/or HMX, was used in the water- or alcohol-wet condition and the nitrocellulose was dissolved in alcohol. The Citroflex A4 was mixed directly with the solid ingredients. On standing, the Citroflex displaced the water, which rose to the surface and was decanted. After further mixing, the batch was rolled

Table 1

Characterization of Nitrocellulose

	HNC 1534	HNC 1534	HNC 942	HNC 947	HNC 983B	DNC D2E	DNC D2W
1. Viscosity (sec) (Ref 3)	198	--	256	96	111	209	240
2. Nitrogen Content (%) (Ref 3)	--	12.29	--	12.32	12.37	--	--
3. Fineness (Ref 3)	--	122	--	--	--	--	--
4. Vacuum Stability Temp (°C)							
90	0.38	--	0.30	0.42	0.41	0.62	1.70
100	1.12	0	1.92	0.92	1.59	11 + (19 hr)	11 + (24 hr)
110	11 + (16 hr)	--	11 + (40 hr)	11 + (16 hr)	11 + (19 hr)		
5. Heat Test (Ref 3)							
65.5°C. Time to:							
Red Fumes (min)	42	--	50	21	60+	32	17
134.5°C. Time to:							
Pink color (min)	35	30	35	30	35	20	25
Red fumes (min)	35	30	40	35	40	20	25
Explosion (min)	300+	--	300+	300+	300+	300+	300+

on a mill. In some cases, the thin sheet material formed at the narrow gap settings or dried unrolled material was extruded into 1/4 x 4 inch strips or 2 x 4 inch blocks.

It was later found that a versatile product could be prepared by a precipitation technique in which a lacquer consisting of nitrocellulose, plasticizer, and stabilizer in butyl or ethyl acetate was added in a fine stream to a vigorously agitated suspension of the particulate explosive and pigment in water. The mixing was conducted at elevated temperatures to rapidly drive off the solvents, with the product recovered by filtration and drying. This material, consisting of discrete particles having a maximum diameter of 1/16 to 1/8 inch, could easily be formed into desired shapes by rolling, extrusion, or pressing.

It was found early in the program that freshly rolled sheets exhibited relatively low densities (about 90% of the theoretical maximum density). However, the density increased to 98-99% of the TMD after a few weeks of aging. Consequently, density determinations usually were not conducted on rolled materials until they had aged at least a week, and preferably two to four weeks. However, material subjected to a vacuum during the extrusion process usually exhibited densities of greater than 99% of the TMD and thus were not aged before density determinations were made.

In the early part of this work, lead chromate, zinc chromate, and lampblack obtained from chemical stores were used in an attempt to prepare a pigment to impart a desired olive-drab color to the flexible explosive. These materials proved to be unsatisfactory. This necessitated a search for suitable lead chromate and lampblack, which was not completed until after many batches had been fabricated and some of the characteristics of the explosive determined. For this reason, some of the examples cited contained pigment with lampblack/chrome yellow ratios outside of the 1/7 to 1/8 ratios finally established as satisfactory. In all, more than 60 experimental batches were prepared to find suitable pigments and proper proportions resulting in a desired olive-drab color. This study established the following pigments as being suitable for use:

Yellow pigments

1. American Cyanamid Co. Chrome Yellow, Med. 40-4500.
2. Sherwin-Williams Co. Chrome Yellow, Med. 12272.
3. Harshaw Chemical Co. 2343 Chrome Yellow Med. 821-778-03.
4. Imperial Color and Chemical Co. X-1810 Standard C.P. Medium Yellow.

5. Imperial Color and Chemical Co. X-2541 Standard C.P. Medium Yellow.

6. Imperial Color and Chemical Co. X-3218 Regal Yellow Medium.

7. The Hilton-Davis Chemical Co. 30-3250 Chrome Yellow Medium.

Lampblack

1. Columbian Carbon Co. Eagle Brand, Germantown Lamp Black.

2. C. K. Williams Co. M-1011 Super Jet Lampblack.

3. Monsanto Chemical Co. Germantown Lamp Black.

4. Mineral Pigments Corp. 8405 Lampblack.

5. Smith Chemical and Color Co. Inc. G.S. Germantown Lamp Black.

The same study established the following pigments as being unsatisfactory:

Yellow pigments (gray mixtures with lampblack were produced).

1. Zinc chromate from chemical stores.

2. Samples of chrome yellow submitted by Mineral Pigment Corp.

Lampblack (yellow mixtures with chrome yellow, medium were produced).

1. Rainbow Standard Black.

2. Lander-Segal Color Co. Black.

This study was not intended to cover the entire field of yellow and black pigments but only those for which samples were easily obtainable. As a result of this study, the pigments chosen for use, largely because of availability, were:

Sherwin-Williams Co. C. P. Chrome Yellow, Medium 12272.

Columbian Carbon Co. Eagle Brand Germantown Lamp Black.

In a few cases, American Cyanamid Co. Chrome Yellow Medium 4-4500 was also used. These pigments were incorporated in the ratios of one part of lampblack to either seven or eight parts of the chrome yellow, medium.

As the work progressed, improvement of the thermal stability of the flexible explosive under development was undertaken through the use of stabilizers. The stabilizer concentration was between 1 and 5% of the total nitrocellulose content. More than 100 batches were prepared to test the effectiveness of the following conventionally used stabilizers:

1. Diphenylamine
2. Ethyl centralite
3. 2-Nitrodiphenylamine
4. 2-Nitrotriphenylamine
5. Zinc oxide
6. Dicyandiamide
7. Carbazole

A series of identical 100-gram mixes were prepared using ingredients from the same stock containers. The stabilizer was added, usually as a solution, with additional solvent, to maintain the solvent level present in each batch. Blanks were prepared by adding solvents without stabilizers to some mixes. All mixes were then processed into 1/4-inch-thick sheets by the aforementioned roll mill process. Not all the conventional stabilizers were effective. In fact, dicyandiamide substantially increased the rate of decomposition of test samples over the entire concentration range at both 100° and 110°C in the vacuum stability test. 2-Nitrodiphenylamine and 2-nitrotriphenylamine appeared to have no effect at 100°C but slightly accelerated decomposition in both the 40-hour test at 110°C and the 16-hour test at 120°C. Zinc oxide showed a tendency to increase decomposition in all phases of the test. Ethyl centralite appeared to be as effective as the diphenylamine (DPA), which was finally selected as a stabilizer primarily because of availability.

Compositions using PETN as the particulate high explosive were prepared in small batches for comparative testing and in larger batches for use in developing a satisfactory method of analysis.

EXPERIMENTAL RESULTS

Testing of the explosives was divided into two categories:

Specification Tests

1. Detonation continuity (Ref 5, par. 4.3.1, and Ref 10)
2. Drop test (Ref 5, par. 4.3.2, and Ref 10)
3. Friction sensitivity (Ref 5, par. 4.3.3)
4. Electrostatic sensitivity (Ref 5, par. 4.3.4)
5. E. R. L. Bruceton impact sensitivity (Ref 5, par. 4.3.5)
6. Exudation at 160°F (Ref 5, par. 4.3.6)
7. Bullet impact (Ref 5, par. 4.3.7)
8. Flame sensitivity (Ref 5, par. 4.3.8)
9. Bar drop impact sensitivity (Ref 5, par. 4.3.9)
10. Density (Ref 5, par. 4.3.10)
11. Elevated temperature (Ref 5, par. 4.3.11)
12. Color, after elevated temperature test (Ref 5, par. 4.3.16)
13. Cold temperature at minus 40°F (Ref 5, par. 4.3.12)
14. Rate of detonation (Ref 5, par. 4.3.13)
15. Vacuum stability (Ref 5, par. 4.3.14)
16. Color change at 160°F (hot water immersion) (Ref 5, par. 4.3.15)
17. Crack after immersion in 160°F water (Ref 4, par. 3.6.1.1)

Non-Specification Tests

1. P.A. impact test (Ref 6, pp 2-4)
2. Explosion temperature test (Ref 6, pp 7, 8)
3. Electrostatic sensitivity test (Ref 6, pp 14, 15)
4. Friction pendulum (Ref 7)
5. Ballistic mortar test (Ref 8)
6. Cap sensitivity (Appendix A)
7. Tensile strength (ASTM std for plastic materials)
8. Compression test (ASTM std for plastic materials)
9. Analysis (Ref 10)
10. Detonation continuity in air (Appendix A)
11. Plate damage (Appendix A)

Variations in tests used to obtain the results noted in this section are given as well as descriptions of those tests not found in readily available publications on explosives. Reference 4, MIL-E-46676 (MU) with Amendment 1, is no longer available, having been superseded by Reference 5, MIL-E-46676A (MU). Formulations for compositions quoted in this section appear in Appendix B.

Specification Tests

1. Detonation Continuity. A 0.08-inch-thick sheet of Composition No. 32 mounted on a 1/4-inch-thick mild steel witness plate was subjected to a hydrostatic pressure of 10,000 psi for 45 minutes and then fired without relieving the pressure. The witness plate was depressed uniformly and showed no plateaus indicative of detonation discontinuity. An M4 cap was used for initiation.

This test and the drop test were both carried out under the supervision of J. L. Uraco, U. S. Naval Weapons Laboratory, Dahlgren, VA.

2. Drop Test. The test cylinders used were loaded with Composition Nos. 32, 33, and 34, which were first rolled separately on a large mill at 130° to 135°F, using a 0.010-gap setting to remove the ethanol and assure homogeneity. They were then consolidated at 0.210-inch gap setting to form 1/4-inch-thick sheets. The sheets thus formed were cut into five-inch diameter discs, which were heated to 145°F and loaded a few at a time into thin-walled steel cylinders (5.020 ± 0.005 inch ID) and pressed at 150 psi. These cylinders comply with BUWEPS Drawing T-30113 (Fig 1, Ref 9).

Cylinders 1, 2, 4, 5, 7, 8, 11, 12, 13, and 14 were subjected to the required five-foot drop. The impact was absorbed by the test cylinders without exhibiting any smoke, flame, or explosion. Cylinders 3, 6, 9, and 10 were subjected to a 10-foot drop. In this test, the drop weight rebounded slightly from the steel stop blocks. Again no smoke, flame, or explosion was exhibited. Radiographic examination showed that the studs on the drop weight had penetrated about 2-7/8 inches into all 14 specimens. No charge breakup or chemical reaction could be detected in the radiographs.

Table 2

Cylinders for drop test

Cylinder No.	Composition No.	Density*
1	[illegible]	
2	[illegible]	
3	32	1.467 g/cc (97.83% TMD)
4	32	
5	32 and 33	
6	32	1.470 g/cc (98.05% TMD)
7	33	
8	33	
9	33	1.463 g/cc (97.58% TMD)
10	33	
11	33 and 34	
12	34	1.470 g/cc (98.05% TMD)
13	33 and 34	
14	34	

*Theoretical maximum density (TMD) is 1.499 g/cc.

3. Friction Sensitivity. This test was run under the supervision of Dr. Charles Dale, Naval Propellants Plant, Indian Head, MD, using a test machine made by the Newman Machine Co., Greensboro, NC.

Twenty tests were run with a starting bearing pressure of 1000 psi. After moving across the test sample with an imparted velocity of eight feet per second, the pressure element came to rest with pressures of 950-980 (avg 960) psi. No smoke, light, or sound was detected emanating from the sample in any of the twenty tests.

4. Electrostatic Sensitivity. The test was run under the supervision of M. Murphy, U.S. Naval Ordnance Laboratory, White Oak, MD, using the Wyatt Test Apparatus.

Tests were made using one microfarad capacitance and E.M.F. values ranging from 2825 to 7500 volts. The energy range tested was from 4 to 28.1 joules, the limit of the apparatus. In no case was smoke, flame, explosion, or any other indication of reaction or decomposition detected.

5. E.R.L. Bruceton Impact Sensitivity. This test was run under the supervision of Harry Heller, U.S. Naval Ordnance Laboratory, White Oak, MD. Twenty-four samples were tested over a drop height range of 101 to 212 cm. The calculations from the test data obtained showed the 50% value to be 138 cm. Previous tests, made in connection with other work, showed 50% values for EL 506 and for pelleted Composition B to be 54 cm and 34 to 39 cm, respectively.

6. Exudation at 160°F*

Composition No.	8	33	EL 506C	Specification
Percent sample loss				
(range)	0.090-0.094	0.088-0.092	0.08-0.20	0.10% max
(avg)	0.092	0.090	0.14	
Percent paper gain				
(range)	--	0.0053-0.0111	0.014	--
(avg)	--	0.0080	0.014	

*This test was shown to be a volatile test rather than an exudation test since the weight gained by the paper was not equal to that lost by the sample.

7. Bullet Impact

Composition No.	31	33	EL 506C	Specification
	No fire or explosion	No fire or explosion	No fire or explosion	No explosion

8. Flame Sensitivity

Composition No.	33	EL 506C	Specification
	No explosion	No explosion	No explosion

9. Bar Drop Impact Sensitivity

Composition No.	31	33	EL 506C	Specification
	No fire or explosion	No fire or explosion	No fire or explosion	No explosion

10. Density (g/cc)

	Composition No.					
	6	8	28	31	32	33
TMD	1.5005	1.5006	1.5005	1.5005	1.4989	1.4989
Density	1.4730	1.4707	1.4699	1.4730	1.4675	1.4879
% TMD	98.17	98.60	97.96	98.17	17.91	99.26

	34	36	37	39	EL 506C	Specification
TMD	1.4989	1.4989	1.5176	1.4989	1.483	1.4 min
Density	1.4630	1.4856*	1.5147	1.4271	1.472	
% TMD	97.61	99.18	99.81	95.21	99.26	

11. Elevated Temperature

Composition No.	33	EL 506C	Specification
After 7 days	No cracks	No cracks**	1/16 in. cracks Maximum
After 42 days***	No cracks	No cracks**	--

*Extruded blocks.

**One DuPont lot, 14 OT 11, developed blisters and many fine cracks during heating which were not related to development of cracks during bending.

***Although not required, the test was continued for 42 days for data.

12. Color (after elevated temperature test)

Composition No.	33	EL 506C	Specification
After 7 days	No change	No change	No change in olive drab color
After 42 dyas	No change	No change	--

13. Cold Temperature at -40°F

Composition No.	8*	33**	EL 506C**	Specification
	Passed	Passed	Passed	Cracks 1/16 inch maximum

14. Rate of Detonation (m/sec)

	Composition No.							
	8	30	32	34	37	38	EL 506C	Specification
Configuration								
1/4 x 1/4 inch	6705	--	--	--	--	--	6940	6600-7500
1/4 x 1/2 inch	6935	7054	6955	6832	7006	7005	6988	--
1/2 x 1/2 inch	6975	--	--	--	--	--	--	--
3/4 x 1 inch	--	7011	--	--	--	--	7001	--

15. Vacuum Stability (ml gas evolved)

	Composition No.								
	8	24	25	26	27	30	31	32	34
Temperature									
90°C	--	--	--	--	--	0.62	--	--	--
100°C	1.01	0.45	0.29	0.30	0.36	1.09	--	0.63	0.42
110°C	5.13	6.33	5.95	5.06	4.00	--	5.04	2.85	4.04

*Sample broke when bent 150° at -50°F but showed no cracks at 90° bend.

**Samples bent 90° showed no cracks at -60°F but broke at -70°F.

	Composition No.					
	37	38	39	40	EL 506C	Specification
Temperature						
90°C	--	--	--	--	0.41	--
100°C	0.66	0.64	0.64	--	1.39	5 max
110°C	2.79	2.76	2.89	2.24	--	--

16. Color Change at 160°F (hot water immersion)

Composition No.	33	EL 506C	Specification
	No change	No change	No change

17. Crack After Immersion in 160°F Water

Composition No.	33	EL 506C	Specification
	None	None	1/16 in. cracks maximum

Non-Specification Tests

1. P.A. Impact Test (inches)*

Composition No.	8	30	31	33	37	38	EL 506C
	14	16	14	16	17	16	14-15

2. Explosion Temperature Test**

Composition No.	8	30	31	33	EL 506C
	268°	258°	268°	250°	248°

*A 2-kilogram drop weight was used.

**Smoke was the indication of decomposition in all cases.

3. Electrostatic Sensitivity Test (joules)

Composition No.	33	EL 506C
	12.3+	12.3+

4. Friction Pendulum (steel shoe)

Composition No.	31	EL 506C
	no crackles, fire or explosion	no crackles, fire or explosion

5. Ballistic Mortar Test (TNT value = 1.00)

Composition No.	8	31	EL 506C
Granular TNT	1.01	--	1.01
Flaked TNT	0.98	1.00	0.98

6. Cap Sensitivity (cap number required for consistent initiation)

Composition No.	8	31	33	37	38	EL 506C
	8	8	8	M6	M6	2 - 8

7. Tensile Strength (at 73°F)**

Composition No.	8	EL 506C	
		Lot No. 14 OT 11	Lot No. DU-L-01
Crosshead speed (in./min)	2.0	2.0	1.5
Max elongation (in.)	5.00	5.45	5.52
Max elongation (%)	83.3	90.7	92.0
Crosshead speed (in./min)	2.0	1.0	0.5
Modulus of elasticity (psi)	248	292	439

*12.3 joules is the limit of the test apparatus.

**See Appendix C for complete test results.

8. Compression Test (at 73°F)*

Composition No.	8	31	14 OT 11	EL 506C DU-L-01	12-OC-01
Crosshead speed (in./min)	1.0	1.0	1.0	1.0	1.0
Max load (lb)	19.6	29.8	36.7	95.8	43.8
Max stress (psi)	26.0	38.0	47.4	64.3	56.4
Modulus of elasticity (psi)	15.1	26.6	210	215	256

9. Analysis

During the early part of this work when DuPont's EL 506C was being characterized, no adequate means of analysis was available for this type of composition. Picatinny Arsenal's Feltman Research Laboratory was therefore authorized to develop procedures suitable for use with these materials. A method developed for PETN-based compositions was found to be also useful for analysis of RDX-based flexible explosives. This is illustrated by the following results.

Composition No.	32	33	34
Nitrocellulose	8.0%	8.0%	8.2%
Citroflex A4	28.1	28.1	28.1
Chrome Yellow	0.8	0.7	0.7
Lampblack	0.1	0.1	0.1
DPA	0.4	0.4	0.4
RDX (by difference)	62.6	62.7	62.5
	100.0%	100.0%	100.0%

10. Detonation Continuity in Air

The values given are for the size cap required to initiate sheets of different thicknesses to complete detonation as shown by visual effects upon steel witness plates.

Composition No.	8	EL 506C (Lot 14 OT 11)
0.08-inch-thick sheet	M6	M6
0.16-inch-thick sheet	Std. No. 6	Std. No. 6
0.25-inch-thick sheet	Std. No. 6	Std. No. 6

*All values obtained at essentially 50% (about 1 inch) compression.

11. Plate Damage

Results of this test in which 3 in. x 10 in. sheets of flexible explosive were detonated on steel witness plates using M6 caps may be judged to a great extent by viewing Figures 1 through 8. The DuPont flexible sheet explosive bears the designation "proprietary explosive" and is identified by a batch number. The nonproprietary replacement developed bears a general name, FXRNC-1. In these FX = flexible explosive, R = RDX, NC = nitrocellulose, and the number 1 indicates the proportions to be RDX 63%, Citroflex A4 plasticizer 28.2%, nitrocellulose 8%, pigment (olive drab) 0.8%, and DPA 0.4%.

Figures 1, 2 and 3 show damage resulting from 0.08-inch-, 0.16-inch-, and 0.25-inch-thick sheets of RDX-based material when 1/4-inch-thick witness plates are used. Figure 7 shows the effect of a 0.25-inch-thick sheet on a 1/2-inch-thick witness plate. Comparing those figures with Figures 4, 5, 6 and 8 shows this nonproprietary material to be a little more effective than EL 506C in cutting the plate, although previous tests, particularly detonation velocity, had not indicated that such should be the case. The figures show that EL 506C tends to leave slightly heavier carbon deposits on the witness plate, but what is not evident from the figures is that FXRNC-1 left depressions with somewhat sharper edges in the plates. This is best seen by comparing Figures 7 and 8, although the edge of the depression in Figure 8 is obscured by the heavy carbon deposit. FXRNC-1 used to obtain the Figures 1, 2, 3 and 7 was Composition No. 8. The EL 506C used in obtaining Figures 4, 5, 6 and 8 was Lot No. 14 OT 11.

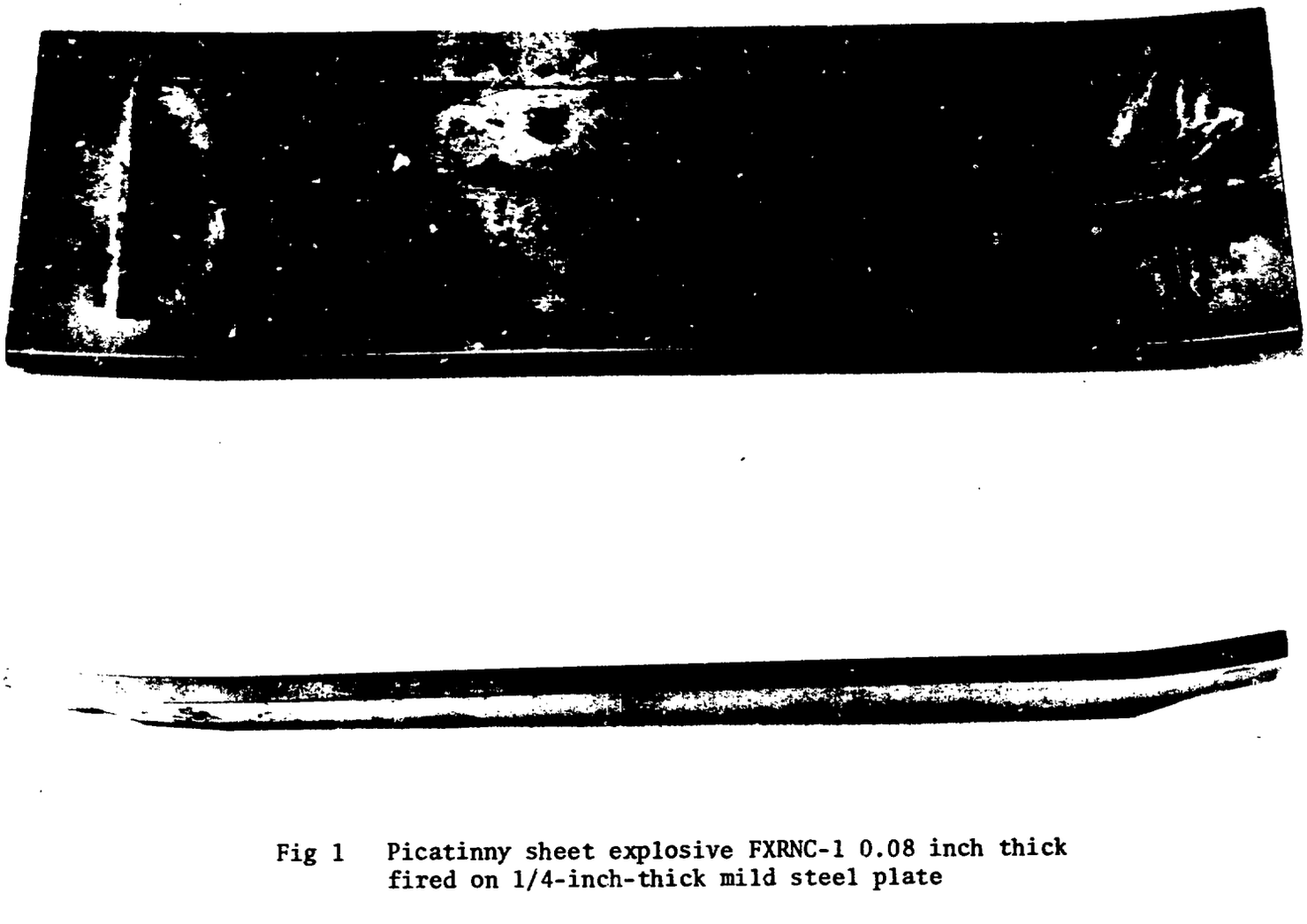

Fig 1 Picatinny sheet explosive FXRNC-1 0.08 inch thick fired on 1/4-inch-thick mild steel plate

Fig 2 Picatinny sheet explosive FXRNC-1 0.16 inch thick fired on 1/4-inch-thick mild steel plate

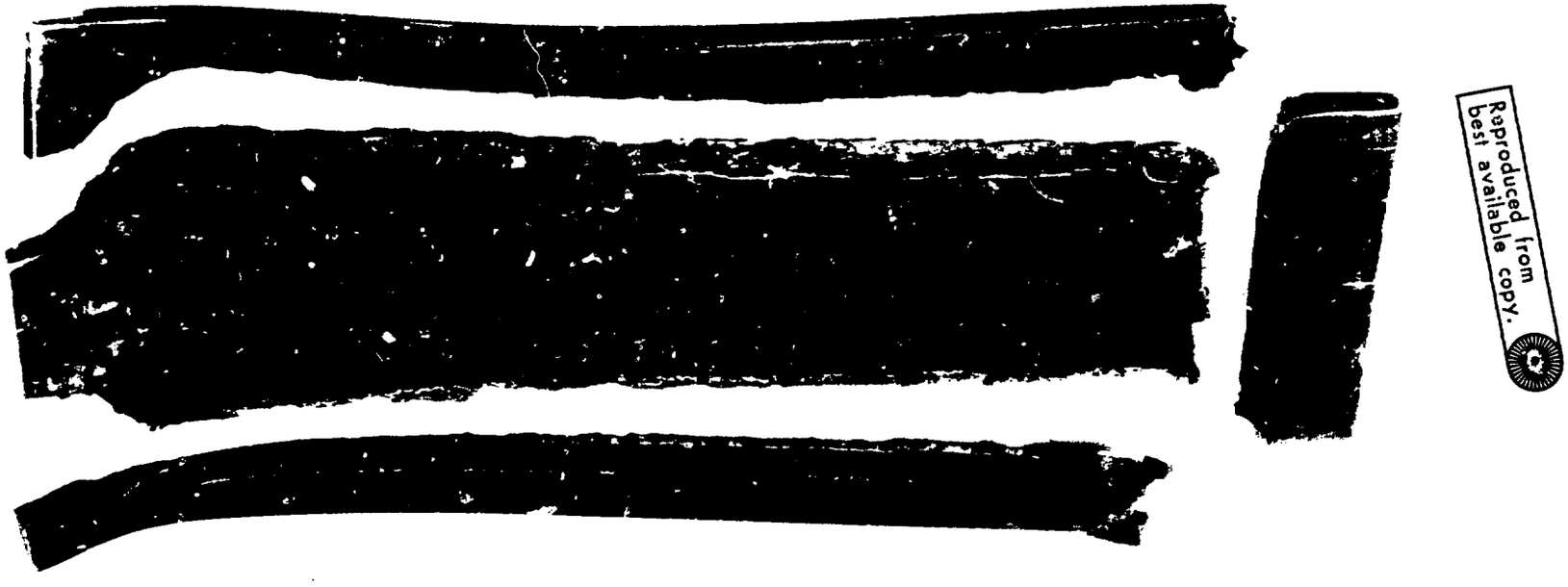

Fig 3 Picatinny sheet explosive FXRNC-1 0.25 inch thick fired on 1/4-inch-thick mild steel plate

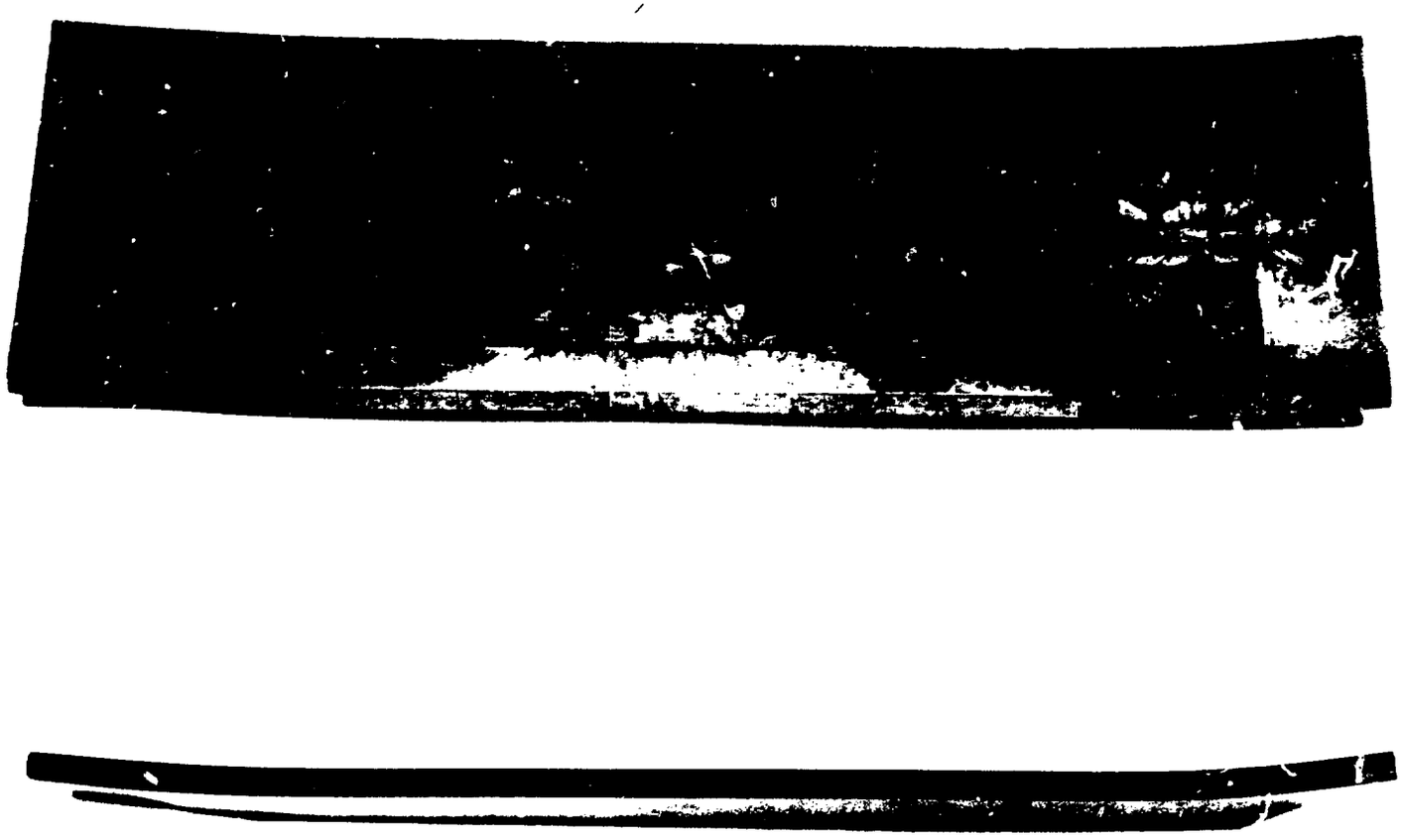

Fig 4 Proprietary sheet explosive 0.08 inch thick fired on 1/4-inch-thick steel plate

Fig 5 Proprietary sheet explosive 0.16 inch thick fired on 1/4-inch-thick mild steel plate

Fig 6 Proprietary sheet 0.25 inch thick fired on 1/4-inch-thick mild steel plate

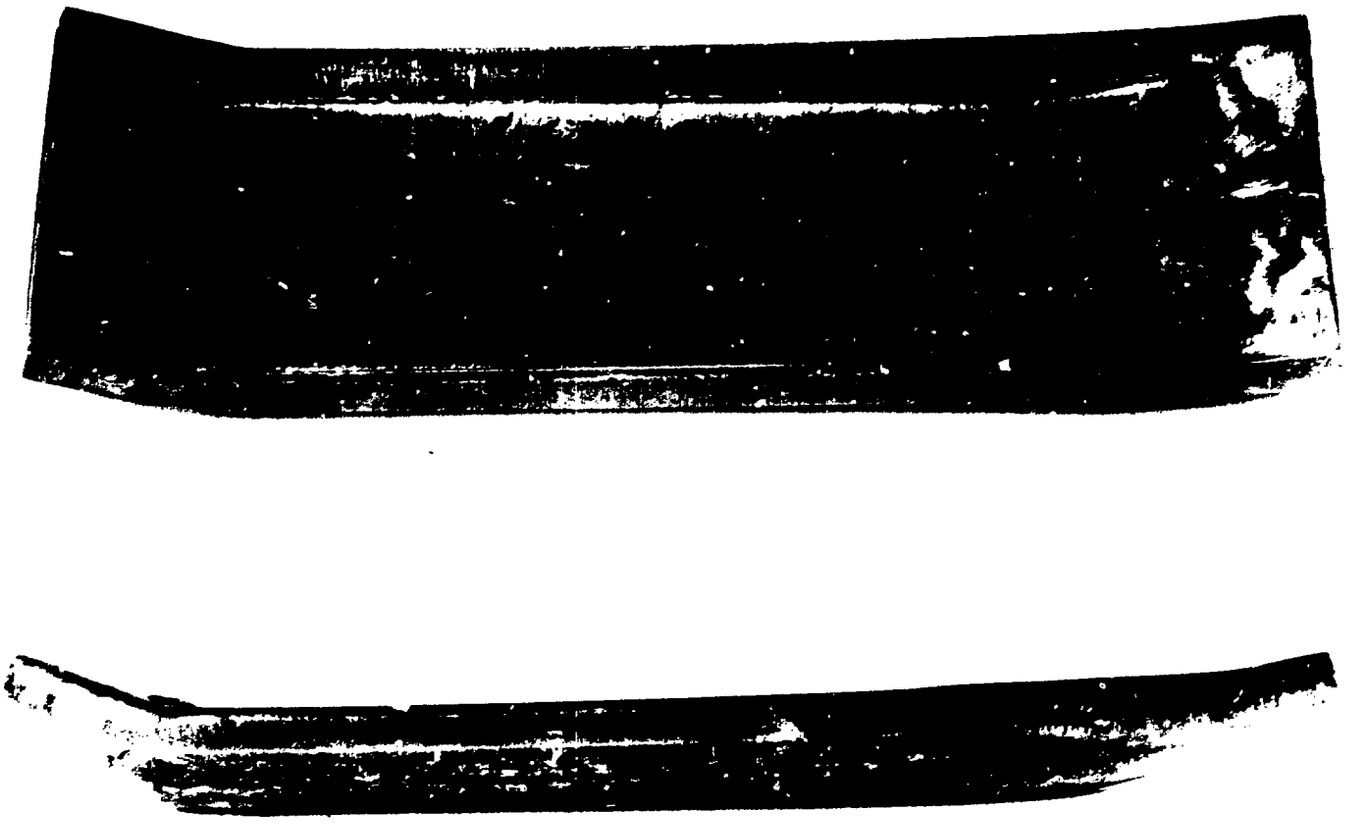

Fig 7 Picatinny sheet explosive FXRNC-1 0.25 inch thick fired on 1/2-inch-thick mild steel plate

Fig 8 Proprietary sheet explosive 0.25 inch thick fired on 1/2-inch-thick mild steel plate

CONCLUSIONS

The work described in this report indicates that RDX- and HMX-based flexible explosive compositions may be preferred to PETN-based composition. Such compositions have been shown to be equal to or superior to the PETN-based composition. In the exudation test, whether a true test of an exudation or a volatiles test, it was found that all experimental samples tested met the specification requirement of 0.10% maximum loss, whereas only one of three lots of EL 506C met the requirement. In the cap sensitivity test, the RDX- and HMX-based compositions were shown to have excellent uniformity of sensitivity to initiation.

The wide range of sensitivity to initiation of EL 506C constitutes a certain hazard not presented by its RDX- and HMX-based analogs. Those compositions showed distinctly greater thermal stability than EL 506C. One unexpected advantage of the RDX-based compositions was the slightly better steel-cutting ability shown in the plate damage tests. This was not expected, as the rate of detonation of RDX-based material had been shown to be slightly inferior to that of EL 506C in 1/4 x 1/4 inch specimens.

REFERENCES

1. RDX, MIL-R-398C, Amendment 2 (MU), 28 April 1971.

2. HMX, MIL-H-45444A, (Ord), Amendment 3, 20 April 1963.

3. Nitrocellulose, MIL-N-244A, Amendment 2 (MU), 30 October 1965.

4. Explosive, Flexible, MIL-E-46676 (MU), 31 October 1962 and Amendment 1, 20 April 1963.

5. Explosive, Flexible, MIL-E-46676A (MU), 17 April 1964.

6. A. J. Clear, Standard Laboratory Procedures for Determining Sensitivity, Brisance, and Stability of Explosives, Picatinny Arsenal Technical Report 3278, April 1970.

7. J. H. McIvor, Friction Pendulum, Picatinny Arsenal Testing Manual 7-1, 8 May 1950.

8. J. H. McIvor, Ballistic Mortar Test, Picatinny Arsenal Testing Manual 7-2, 8 May 1950.

9. J. L. Graco, Drop and Detonation Continuity Tests of Picatinny Arsenal's Flexible Explosive, U.S. Naval Weapons Laboratory Technical Memorandum No. T-17/65, June 1965.

10. R. Atno, Flexible Explosive Composite of Lots P.A. 1-1 Through 1-17, Picatinny Arsenal Laboratory Report AL-P-292-68, 24 September 1968.

11. F. B. Wells, Some Properties of the Flexible Explosive EL 506C, Type 2, Picatinny Arsenal Technical Report 4612, February 1974.

APPENDIX A

Notes as to variations in the tests outlined in the references and a full description of tests not found in readily available publications on explosives are given here.

Specification Tests

Density (Ref 5, par. 4.3.10)

The volume of each specimen used in density determinations was obtained by the standard water displacement method.

Rate of Detonation (Ref 5, par. 4.3.13)

In carrying out this test, three to five specimens were used. The ends of the casings on the chromograph contacts were removed to expose the pin switches within. The contacts were then inserted into the holes in the bar so that the pin switches were exactly perpendicular to the longitudinal axis of the bar and protruded about 1/32 inch. In this way the pin switches were actually imbedded in the test specimen when it was positioned on the bar later. The electronic counter used is known as a "Rastergraph" and records tenths of a nanosecond on film. Center-to-center distances between pin switches were determined on a shadowgraph which is graduated to 0.001 inch.

Crack After Immersion in 160°F Water (Ref 4, par. 3.6.1.1)

The flexible explosive shall not crack more than 1/16 inch in depth when tested as follows: The specimen shall be immersed in a water bath maintained at 160° plus or minus 5°F for 24 hours. Then the specimen shall be removed from the water bath and within two minutes bent 90° on a 3/4-inch-wide mandrel with a bending time of five seconds. The specimen shall then be measured for cracks perpendicular to the mandrel. If any specimen fails to meet the requirement noted above, the lot shall be rejected.

Non-Specification Tests

P.A. Impact Test (Ref 6, pp. 2-4)

Flexible sheet explosive obviously cannot be granulated. Test samples, therefore, were prepared in disc form small enough to fit the cup and thick enough to weigh 30 ± 5 mg.

Explosion Temperature Test (Ref 6, pp. 7 and 8)

The test equipment used was of larger capacity than that noted in the reference. It was also equipped with a stirrer and used 50/50 solder as the metal bath material. Since the flexible explosive cannot be granulated, as is required by the reference, it was cut into very small pieces which were dropped into the cap until the proper weight of test sample had been added. In most of these tests, the cap containing the specimen was placed in a swivel holder which allowed for remote immersion without the need to hold the cap with tongs.

Friction Pendulum (Ref 7)

In this test, since the samples could not be granulated as required by the reference, pieces about 1/4 x 1/4 x 2 inches were used.

Ballistic Mortar Test (Ref 8)

For this test, flexible explosive samples were prepared by cutting discs just under 1-1/8 inch in diameter from 1/4 inch thick sheets. One such disc was then placed in the bottom of the cup. Additional discs, each with a hole in the center just large enough to allow for insertion of the detonator, were then added until the approximate desired weight of sample was attained. Additional very thin slices were then pressed on top of the upper disc until the exact desired sample weight was obtained. The detonator was then inserted into the charge until it rested firmly on the solid disc in the bottom of the cup. The procedure described in the reference was followed thereafter.

Cap Sensitivity

The cap sensitivity test determines the smallest standard cap which will cause a test sample to detonate completely. Caps used in this test contained the following charges:

Cap No.	Charge
	Dextrinated Lead Azide
1	0.30 g
2	0.40 g
3	0.54 g
4	0.65 g
5	0.80 g
6	1.00 g
7	1.50 g
8	0.25 g plus 0.55 g PETN*
M6	0.270-0.062 g plus 0.943-0.130 g RDX**

Caps No. 1 through 8 were procured from the Trojan Powder Company of Allentown, PA. Such caps are carefully hand made to assure uniformity of charge.

In this test, 1/4-inch-thick strips of flexible explosive one inch wide by 10 inches long were used. The detonator cap was taped into a 1/4 inch wide x 3/4 inch deep notch cut into the center of one end of the test strip. In early tests, two-foot-long pieces of 40- or 50-grain primacord telltale were taped into a 1/4 inch deep x 1/4 inch wide notch cut into the opposite end. It was found that there was no need for the telltale, and it was eliminated. Firings on a heavy steel plate left sufficient marks to show complete or incomplete detonation, and undetonated portions of sample were easily seen.

The cap sensitivity is given as the smallest cap that will cause complete detonation in five consecutive test firings.

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*This charge is equivalent in initiating power to two grams dextrinated lead azide.

**See P.A. Ord. Corps Drawing No. 8830972.

Detonation Continuity in Air

In this test, the smallest cap required to fire 3 x 10 inch sheets of explosive 0.08, 0.16, and 0.25 inch thick was used. These sheets are centered on 1/4 inch thick, 4 x 12 inch steel witness plates. The 0.08-inch thick sheets were fired with the detonating cap inserted about 3/4 inch under the center of one end of the test sheet. For thicker sheets, the detonator cap is inserted into a 1/4 inch wide x 3/4 inch deep slot cut into the center of one end of the test sheet.

Plate Damage

This test is designed as a small scale visual means of comparing the relative demolition potential of explosives, especially sheet explosives. In the test, 3 x 10 inch sheets of explosive of various thicknesses are placed on 4 x 12 inch steel witness plates which usually are 1/4 inch thick. Where the explosive is powerful enough to largely destroy the 1/4-inch-thick plate, a thicker one is used. In all tests, an M6 cap, applied as described in the preceding paragraph, was used as an initiator. Figures 1 through 8 show the effects on steel plate obtained with the nonproprietary sheet explosive developed and with EL 506C.

APPENDIX B

EXPERIMENTAL FORMULATIONS

Composition No. 1 and 2

Ingredients	Percent	Weight, g
RDX 3-57	63.0	31.5
Nitrocellulose HNC 1534	8.0	4.0
Citroflex A4	28.2	14.1
Pigment*	0.8	0.4

Composition No. 1 was worked by hand, air dried for 48 hours, and again hand worked to give a material which, although not completely homogeneous, closely resembled a similarly worked portion of EL 506C except for color. The RDX crystals reflected sunlight, while few reflections were seen in the DuPont material. For Composition No. 2 the RDX and Citroflex were mixed for 20 minutes at 130°F, with three drops of water being removed by squeezing. The nitrocellulose was added and mixed for 20 minutes prior to the addition of the pigment, resulting in a yellow, crumbly material after five additional minutes of mixing. After the composition was dried for an hour at 65°C and exposed it to air overnight, the alcohol odor was still present. Hand working rendered the explosive similar in texture to the DuPont material. Again light reflection was noticeable because the particle size of RDX was greater than that of the PETN in the DuPont material.

Composition No. 6

Ingredients	Percent (dry basis)	Weight, g
RDX 545-62 (20% water)	63.0	393.75
Citroflex A4	28.2	141.0
Nitrocellulose HNC 1534 (30% ethanol)	8.0	57.14
Pigment (1/10 Lampblack/$PbCrO_4$)	0.8	4.0
Ethanol	--	13.0

After the RDX and Citroflex A4 were mixed for two minutes at 130°F in a one-half liter sigma blade blender, the mixer was stopped and tilted to remove excess water (79 grams recovered). The remaining ingredients were added and mixed for 30 minutes. After five minutes, material began to be ejected from the blender. This

*Composition No. 1, 1/15 lampblack/lead chromate; Composition No. 2, 1/31 lampblack/lead chromate.

necessitated the use of the cover for 15 minutes, after which the cover was removed. The mix was then rolled in five portions at 130-135°F using a 0.010-inch gap for an additional two minutes after all odor of ethanol had disappeared. These sheets were consolidated on a roll mill at 135°F with a gap of 0.200 inch to give 1/4-inch sheets gray in color. When cool, the product was tough and rubbery with very little reflection of sunlight from crystalline particles of RDX.

Composition No. 8

Eight 500-gram batches were prepared exactly like Composition No. 6 except that a 1/13 pigment ratio was used. This material, in the form of a 1/4-inch-thick sheets, was tough, rubbery and gray in color.

Composition No. 24 - 27

Ingredients	24	25	26	27
	(parts by weight)			
RDX 545-62	63.0	63.0	63.0	63.0
Citroflex A4	28.2	28.2	28.2	28.2
Nitrocellulose (HNC 1534)	8.0	8.0	8.0	8.0
DPA	--	0.08	0.24	0.40
Pitment (1/7 lampblack/ $PbCrO_4$)	0.8	0.8	0.8	0.8
Ethanol (ml)	25	20	15	10

As noted previously, it was found that diphenylamine (DPA) and ethyl centralite serve as stabilizers for compositions of the type under investigation, but only within the 1-5% limit of nitrocellulose content. The four compositions shown incorporated a 2% solution of DPA in ethanol, with Composition 24 prepared as a control. Two, six, and ten milliliters of the DPA solution were added to Compositions 25, 26, and 27, respectively, to result in a 1%, 3%, and 5% DPA level (based on the nitrocellulose present). These compositions were utilized in the vacuum stability test with the results described in Experimental Results.

Composition No. 28

Composition No. 28 was identical to Composition No. 6 except that batch HNC 923 nitrocellulose was used instead of HNC 1534 and the ratio of lead chromate/lampblack was reduced from 10/1 to 8/1. Ten mixes of this composition resulted in smooth, tough, rubbery, olive-drab colored sheets of flexible explosive.

Composition No. 30

Composition No. 30 was identical to Composition No. 27 except that batch HNC 947 nitrocellulose was used instead of HNC 1534 and the ratio of lead chromate/lampblack was increased from 7/1 to 8/1. The material was rolled on a small mill using a gap setting of 0.240 inch.

Composition No. 32 - 33

Compositions No. 32 - 33 were identical to Composition No. 30 except that batch HNC 942 nitrocellulose was used instead of HNC 947. This 80-pound mix was prepared in a 20-gallon sigma blade mixer. After removal from mixer, this material was stored before rolling.

Composition No. 34

Composition No. 34 was identical to Composition No. 30.

Composition No. 35

Ingredients	Percent	Weight, g
RDX 545-62	62.76	63.0032
Citroflex A4	28.09	28.2003
Nitrocellulose HNC 942	7.95	7.9791
Lampblack (Columbian Carbon)	0.09	0.0889
Chrome Yellow, Medium (Sherwin Williams)	0.71	0.7109
DPA (purified)	0.40	0.4003
	100.00	100.3827

This composition was made using the utmost care in weighing and adding the ingredients. Composition No. 35 was utilized to determine the applicability of a method developed by the Analytical Laboratory of the Feltman Research Laboratory for analysis of the DuPont PETN -based flexible explosive (EL 506C) on RDX-based flexible explosives. All ingredients were first dried to constant weight over concentrated sulfuric acid before being used in mix.

Composition No. 36

Composition No. 36 was identical to Composition No. 30; however, the RDX and Citroflex were first mixed in a 20-gallon sigma blade blender at 135°F for two minutes. The other ingredients, including two pounds of ethanol, were added and mixing continued for three minutes. The composition was loosened from blender walls to assure uniform mixing. With the addition of one pound of ethanol, the whole mix was blended for 30 minutes. It was then removed from the mixer, air-dried for 24 hours at 125 to 135°F, and extruded at 135 to 145°F. Both 2 x 4 inch blocks, 12 and 24 inches long, and 1/4 x 3 inch strips, 12 and 24 inches long, were formed.

Composition No. 37

Ingredients	Percent	Weight, g
RDX 545-62	33.4	167
HMX 655-61	29.6	148
Citroflex A4	28.2	141
Nitrocellulose HNC 983B	8.0	40
2NDPA	4.0	2
Pigment	0.8	4

This material was prepared like other compositions except that the particulate high explosive present was essentially a 50/50 mixture of RDX and HMX.

Composition No. 38

Ingredients	Percent	Weight, g
HMX 655-61	63.0	315
Citroflex A4	28.2	141
Nitrocellulose HNC 983B	8.0	40
DPA	0.4	2
Pigment	0.8	4

Four batches of this composition were blended before passing through the roll mil. The product formed was smooth, tough, rubbery, and olive-drab in color. It exhibited very little reflection of light, unlike compositions 1, 2, and others containing RDX 3-57.

Composition No. 39

Composition No. 39 was identical to Composition No. 38 except that the nitrocellulose was dissolved in 588 grams of butyl acetate with mechanical stirring provided by a Cowles Dissolver. Citroflex A4 and DPA were then added to form a lacquer. This lacquer was added in a fine stream to a vigorously agitated suspension of HMX and pigment in distilled water (5.544 ml maintained at 80°C). When all the lacquer had been added, the vigorously agitated suspension was heated to 95-98°C to drive off all solvents. The composition was then quenched to 40°C by passing 16° water through the jacket of the mixing kettle. The agitator was stopped, the mixture was allowed to settle, and most of the water decanted. The residual water was removed by filtration to provide a granular product having maximum dimensions of 1/64 to 3/16 inch. This material was air-dried overnight and then oven-dried to produce granules that did not agglomerate at room temperature. Roll milling produced a smooth, tough, rubbery, olive-drab sheet.

Composition No. 40

Composition No. 40 was identical to Composition No. 30 except that batch HNC 983B nitrocellulose was used instead of HNC 947, and the material processed the same as Composition No. 39, with the RDX and pigment suspended in 3780 ml distilled water. A portion of the mix was compression-molded into small billets at 145°F.

APPENDIX C

Tensile Strength Tests

Values shown are the average of duplicate test results of Composition No. 8 at 73°F.

Crosshead Speed (in./min)	Max Load (lb)	Max Stress (psi)	Elongation at Rupture (in.)	(%)	Modulus of Elasticity (psi)	Work Developed at Max Stress (ft-lb/in.^{3})	Modulus Based on Max Stress (psi)
0.05	5.90	16.1	1.84	35.6	221	0.314	4.51
0.5	7.55	20.3	3.78	63.0	229	0.867	11.8
1.0	8.33	21.7	4.38	72.9	277	1.06	9.19
1.5	9.75	24.2	4.55	75.9	241	1.21	10.6
2.0	9.5	24.9	5.0	83.3	249	1.24	12.3

Compression Tests

Compression test of Composition No. 8 at 73°C using a crosshead speed of one inch per minute. Values given are the average of five test results.

Max Load (lb)	Max Stress (psi)	Deformation at Max Load (in.)	(%)	Modulus Elasticity (psi)	Work* Developed (ft-lb/in.^{3})	Modulus Based on Max Stress (psi)
19.6	25.0	1.000	52.4	216	0.882	15.7

Compression tests of Composition No. 31 at a crosshead speed of one inch per minute. Values shown are the average of five test results.

Temp (°F)	Max Load (lb)	Max Stress (psi)	Deformation at Max Load (in.)	(%)	Modulus of Elasticity (psi)	Work** Developed (ft-lb/in.^{3})	Modulus Based on Max Stress (psi)
-80	2673	3389	0.398	16.3	44896	33.6	2409
-40	1417	1829	0.722	37.9	5454	33.3	829
0	1067	1379	0.888	47.3	3164	27.5	547
73	29.8	38.0	1.000	53.8	220	1.34	26.6
125	14.0	17.9	1.000	53.4	130	0.597	11.5
160	11.4	14.6	1.000	53.5	127	0.526	8.0

*Calculations made at 1.000 inch (about 50%) deformation.

**Calculations were made at max load for samples tested at -80°, -40°, and 0°F. Calculations were made at 1.000 inch (about 50%) deformation for samples tested at 73°, 125°, and 160°F.